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STATIC FORCE TESTS OF CONIC AND BICONIC BODIES AT MACH NUMBER 10

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AIR FORCE SYSTEMS COMMAND
ARNOLD AIR FORCE STATION, TENNESSEE

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A static force test was conducted in the hypersonic Mach number regime to obtain experimental aerodynamic data on conic and biconic bodies. The test was performed at a nominal Mach number of 10 at a free-stream unit Reynolds number of one million per ft. The angle-of-attack range was -14 to 14 deg. Model flow-field photographs and oil-flow photographs were obtained on several configurations at selected model attitudes and test conditions.

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NOMENCLATURE

AB	Model base area; 75.784 $in.^2$ (CODE 1, 2, and 5), 72.02 $in.^2$ (CODE 3), or 69.912 $in.^2$ (CODE 4)
ALPHA	Model angle of attack, deg
ALP-1I	Indicated sector pitch angle, deg
BALCAL	Balance number and calibration number
BETA	Model sideslip angle, deg
CAB	Base axial-force coefficient, - (PBA - P8)(AB)/(Q8 • S), body axes
CA	Forebody axial-force coefficient, CAT - CAB, body axes
CAT	Total axial-force coefficient, total axial force/(Q8 • S), body axes
CLL	Rolling-moment coefficient, rolling moment/(Q8 • S •L), body axes
CLM	Total pitching-moment coefficient, total pitching moment/(Q8 • S • L), body axes
CLMF	Forebody pitching-moment coefficient, CLM + (CAB)(ZB/L), body axes
CLN	Yawing-moment coefficient, yawing moment/(Q8 • S • L), body axes
CN	Normal-force coefficient, normal force/(Q8 • S), body axes
CR	Center-of-rotation of pitch mechanism, in.
CODE	Model configuration number
CONFIGURATION	Configuration description
CY	Side-force coefficient, side force/(Q8 • S), body axes
DLP	Data loop period, sec
GROUP	Data polar number
L	Model moment reference length, base diameter, 9.823 in.
MACH	Free-stream Mach number

NO	Data point number
PB1 thru PB6	Base pressures, psia
PBA	Average base pressure, psia
PHI-I	Indicated sector roll angle, deg
PHI-T	Model roll angle, deg
PO	Tunnel stilling chamber pressure, psia
P8	Free-stream static pressure, psia
Q8	Free-stream dynamic pressure, psia
RE/FT	Free-stream unit Reynolds number, ft^{-1}
RNOSE	Model nose radius, in.
S	Model reference area, 75.784 $in.^2$ ($\pi L^2/4$)
SLICES	Number of slices on top aft portion of the model
TIME	Time at which data point was taken, hr:min:sec
TO	Tunnel stilling chamber temperature, °R
T8	Free-stream static temperature, °R
ZB	Vertical distance from model x-axis to the centroid of the base area, positive if the centroid is below the x-axis at PHI-T = 0; 0 (CODE 1, 2, and 5), 0.227 in. (CODE 3), or 0.348 in. (CODE 4)

1.0 INTRODUCTION

The work reported herein was conducted by the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), under Program Elements 65807F and 63311F, Control Number 627A-00-8. The project was sponsored in part by SAMSO/RSSE. The results were obtained by ARO, Inc., AEDC Division (a Sverdrup Corporation Company), operating contractor for the AEDC, AFSC, Arnold Air Force Station, Tennessee. The test was conducted in the von Karman Gas Dynamics Facility (VKF), under ARO Project No. V41C-33. Project monitors were Capt. R. J. Chambers and Mr. E. R. Thompson for SAMSO and AEDC, respectively. Dr. M. O. Varner was the principal research investigator for ARO.

The objective of the test was to provide a laminar-flow data base to validate and develop analytical codes to be used in predicting the hypersonic aerodynamic characteristics of conic and biconic bodies with single and multiple flat surfaces.

Static-stability and axial-force data and oil flow data were obtained during the test. Data were obtained at a Mach number of 10 and a free-stream unit Reynolds number of one million per ft. The angle-of-attack range was -14 to 14 deg. The effects of nose radius and single and double flat surfaces were investigated. Oil flow visualization data were acquired on the double flat surface configuration to determine the flow directions in the vicinity of the double flat surface.

Inquires to obtain copies of the test data should be directed to either SAMSO/RSSE, P. O. Box 92960, Worldway Postal Center, Los Angeles, CA. 90009 or AEDC/DOTR, Arnold AFS, TN. 37389, Attn: Mr. E. R. Thompson.

2.0 APPARATUS

2.1 TEST FACILITY

Tunnel C (Fig. 1) is a closed-circuit, hypersonic wind tunnel with a Mach number 10 axisymmetric contoured nozzle and a 50-in.-diam test section. The tunnel can be operated continuously over a range of pressure levels from 200 to 2000 psia with air supplied by the VKF main compressor plant. Stagnation temperatures sufficient to avoid air liquefaction in the test section (up to 1900°R) are obtained through the use of a natural gas fired combustion heater in series with an electric resistance heater. The entire tunnel (throat, nozzle, test section, and diffuser) is cooled by integral, external water jackets. The tunnel is equipped with a model injection system, which allows removal of the model from the test section while the tunnel remains in operation. A description of the tunnel may be found in the Test Facilities Handbook*.

*Test Facilities Handbook (Tenth Edition). "von Karman Gas Dynamics Facility, Vol. 3." Arnold Engineering Development Center, May 1974.

2.2 TEST ARTICLE

The two basic models tested were a 7-deg cone model and a 14/7-deg biconic model with a 0.5-in.-radius nose. The 7-deg cone model was tested with either a sharp nose (CODE 1) or a 0.5-in.-radius nose (CODE 5). The blunted, 14/7-deg biconic model was tested with no flat surfaces (CODE 2), one flat surface (CODE 3), or two flat surfaces (CODE 4) at the top, aft end of the model. Details of the models are presented in Fig. 2 and an installation sketch of the sharp, 7-deg cone model is shown in Fig. 3.

2.3 TEST INSTRUMENTATION

2.3.1 Test Conditions

Tunnel C stilling chamber pressure is measured with a 500- or 2500-psid transducer referenced to a near vacuum. Based on periodic comparisons with secondary standards, the accuracy (a bandwidth which includes 95-percent of the residuals, i.e 2σ deviation) of the transducers is estimated to be within ±0.16 percent of pressure or ±0.5 psi, whichever is greater, for the 500-psid range and ±0.16 percent of pressure or ±2.0 psi, whichever is greater, for the 2500-psid range. Stilling chamber temperature measurements are made with CR-AL thermocouples which have an uncertainty of ±(1.5°F + 0.375 percent of reading).

2.3.2 Test Data

Model forces and moments were measured with a six-component, strain-gage balance (see Table 1) calibrated by VKF. Prior to the test, static loads in each plane and combined static loads were applied to the balance to simulate the range of loads and center-of-pressure locations anticipated during the test. The range of check loads applied and the measurement accuracies are given in Table 1. The accuracies represent the bands of 95 percent (2σ deviation) of the measured residuals, based on differences between the applied loads and the corresponding values calculated from the balance calibration equations included in the final data reduction.

The standard base pressure system uses 1-psid transducers referenced to a near vacuum. Based on periodic comparisons with secondary standards, the estimated accuracy is ±0.3 percent of pressure or ±0.0015 psi, whichever is greater.

Model flow-field shadowgraphs were obtained on each configuration tested at selected model attitudes and test conditions. Oil flow photographs were obtained on one configuration at several attitudes.

3.0 TEST DESCRIPTION

3.1 TEST CONDITIONS AND PROCEDURES

3.1.1 General

A summary of the nominal test conditions is given below.

MACH	PO, psia	TO, °R	Q8,psia	P8,psia	RE/FT x 10^{-6}
10.0	666	1710	1.07	0.015	1.0
10.0	804	1900	1.27	0.018	1.0

A test summary showing all configurations tested and the variables for each is presented in Table 2.

In the VKF continuous flow wind tunnels (A, B, C), the model is mounted on a sting support mechanism in an installation tank directly underneath the tunnel test section. The tank is separated from the tunnel by a pair of fairing doors and a safety door. When closed, the fairing doors, except for a slot for the pitch sector, cover the opening to the tank and the safety door seals the tunnel from the tank area. After the model is prepared for a data run, the personnel access door to the installation tank is closed, the tank is vented to the tunnel flow, the safety and fairing doors are opened, and the model is injected into the airstream, and the fairing doors are closed. After the data are obtained, the model is retracted into the tank and the sequence is reversed with the tank being vented to atmosphere to allow access to the model in preparation for the next run. The sequence is repeated for each configuration change.

3.1.2 Data Acquisition

Data were recorded in either the point-pause or sweep mode of operation, using the Model Attitude Control System (MACS). The mode for each data group is identified in the test summary (Table 2).

The point-pause data were obtained for finite values of ALPHA and PHI-T with a delay before each data point to allow the base pressures to stabilize. Each data point for this mode of operation represents the resultant of a Kaiser-Bessel digital filter utilizing 16 samples taken over a time span of 0.33 sec.

The continuous sweep data were obtained for a fixed value of PHI-T with a sweep (ALPHA) rate of 1 deg/sec. A data sample was recorded every 0.0277 sec and 16 samples were applied to a Kaiser-Bessel digital filter to produce a data point every 0.028 deg in pitch. The data were then interpolated to obtain the data at the requested model attitudes. If applicable, the base pressures were obtained from a curve fit of data obtained during the point-pause mode to calculate the base axial force coefficient.

3.2 DATA REDUCTION

The model static force data were obtained as described in Section 3.1. The force and moment measurements were reduced to coefficient form using the digitally filtered data points and correcting for first and second order balance interaction effects. These coefficients were also corrected for model tare weight and balance-sting deflections. Model attitude and tunnel stilling chamber pressure were also calculated from digitally filtered values.

Model aerodynamic force and moment coefficients are presented in the body axes. Pitching and yawing moment coefficients are referenced to the model base. Model base diameter (9.823 in.) and base area (75.784 in.^{2}) were used as the reference length and area for the model aerodynamic coefficients.

3.3 UNCERTAINTY OF MEASUREMENTS

3.3.1 General

The accuracy of the basic measurements (PO and TO) was discussed in Section 2.3. Based on repeat calibrations, these errors were found to be

$$\frac{\Delta PO}{PO} = 0.0016 = 0.16\%, \quad \frac{\Delta TO}{TO} = 0.004 = 0.4\%$$

Uncertainties in the tunnel free-stream parameters and the model aerodynamic coefficients were estimated using the Taylor series method of error propagation, Eq. (1),

$$(\Delta F)^2 = \left(\frac{\partial F}{\partial X_1}\Delta X_1\right)^2 + \left(\frac{\partial F}{\partial X_2}\Delta X_2\right)^2 + \left(\frac{\partial F}{\partial X_3}\Delta X_3\right)^2 \cdots + \left(\frac{\partial F}{\partial X_n}\Delta X_n\right)^2 \qquad (1)$$

where ΔF is the absolute uncertainty in the dependent parameter $F = f(X_1, X_2, X_3 \ldots X_n)$ and X_n are the independent parameters (or basic measurements). ΔX_n are the uncertainties (errors) in the independent measurements (or variables).

3.3.2 Test Conditions

The accuracy (based on 2σ deviation) of the basic tunnel parameters, PO and TO, (see Section 2.3) and the 2σ deviation in Mach number determined from test section flow calibrations were used to estimate uncertainties in the other free-stream properties using Eq. (1). The computed uncertainties in the tunnel free-stream conditions are summarized in the following table.

	Uncertainty, (±) percent of actual value			
PO, psia	MACH	P8	Q8	RE/FT
666	1.2	8.0	5.6	3.4
804	0.8	5.3	3.7	2.3

3.3.3 Test Data

The uncertainties of the aerodynamic coefficients are presented in the following tables. These were established at the maximum aerodynamic loading condition using the Taylor series method of error propagation (Eq. 1) with the independent variables determined from the accuracy of the six component balance (listed in Section 2.3), the accuracy of the base pressure transducer (Section 2.3), and the uncertainties in the tunnel parameters (P8, Q8) listed in Section 3.3.

Maximum Coefficient Uncertainty (±)

PO, psia	CN	CLM	CY	CLN	CLL	CAT	CA
666	0.030	0.040	0.0062	0.010	0.00027	0.0087	0.0093
804	0.019	0.023	0.0052	0.008	0.00024	0.0061	0.0066

The basic precision of the aerodynamic coefficients was also computed using only the balance and base pressure accuracies listed in Section 2.3 along with the nominal test conditions, using the assumption that the free-stream flow nonuniformity is a bias type of uncertainty which is constant for all test runs. These values therefore represent the data repeatability expected and are especially useful for detailed discrimination purposes in parametric model studies.

Coefficient Repeatability (±)

PO, psia	CN	CLM	CY	CLN	CLL	CAT	CA
666	0.0062	0.010	0.0062	0.010	0.00019	0.0047	0.0040
804	0.0052	0.009	0.0052	0.008	0.00015	0.0041	0.0033

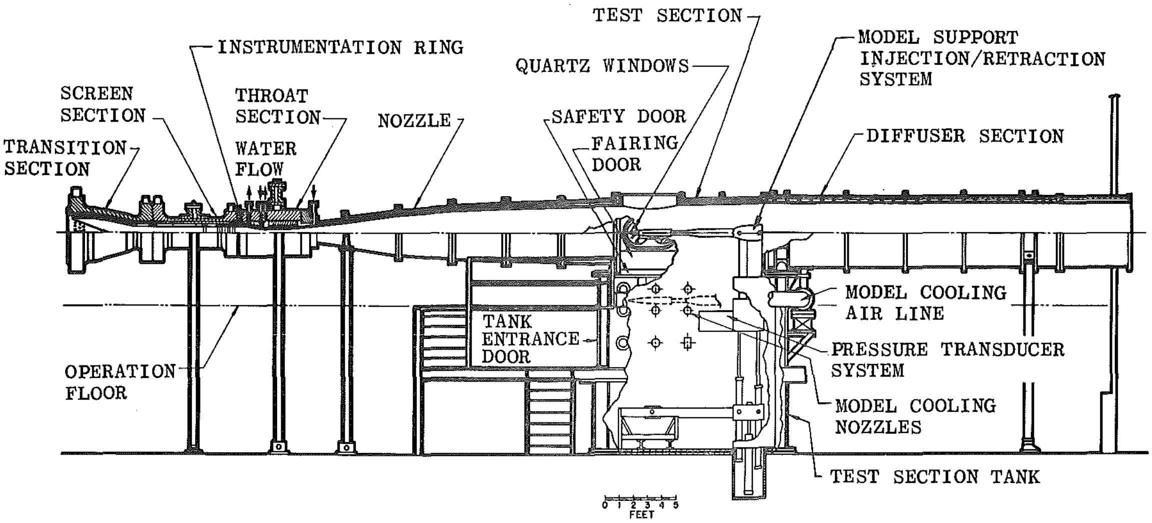
The uncertainty in model angle of attack (ALPHA), as determined from calibrations and consideration of the possible errors in model deflection calculations, is estimated to be ±0.1 deg.

4.0 DATA PACKAGE PRESENTATION

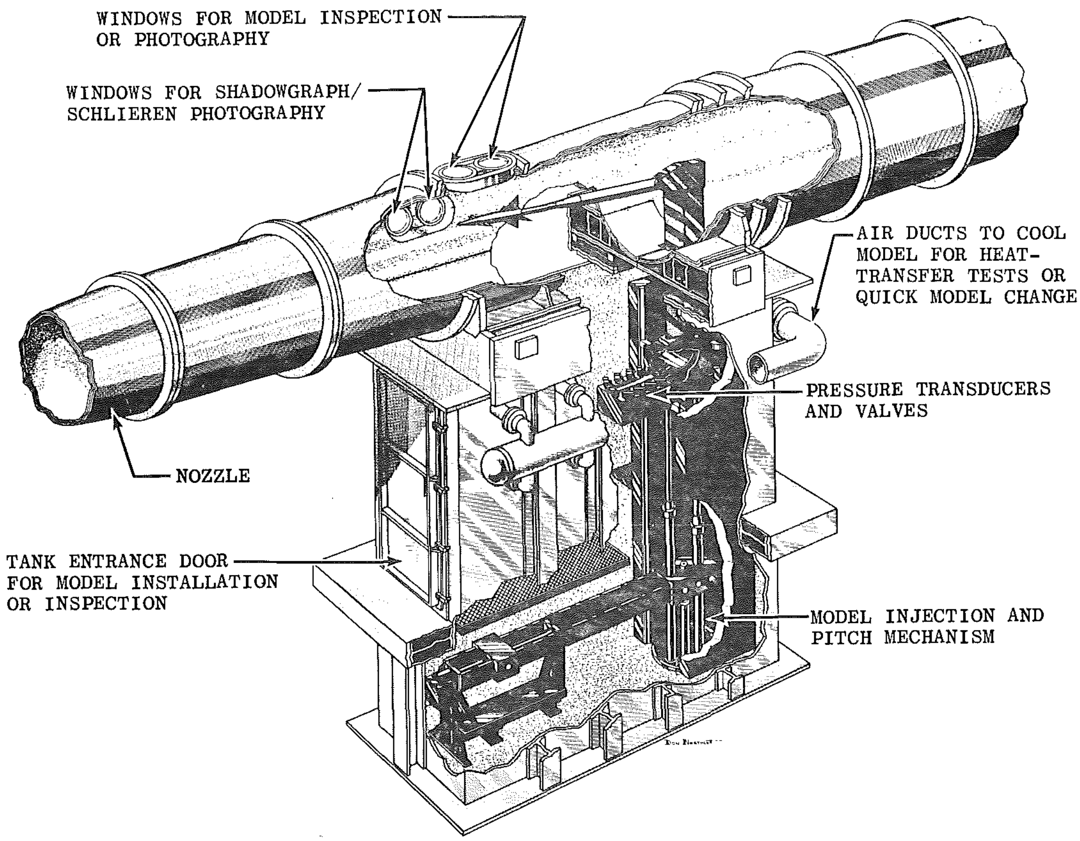
The static-stability and axial-force characteristics of the three biconic configurations are shown in Fig. 4 and are typical of the test results which were obtained. Tabulated model aerodynamic force and moment data are presented in the body axes. Base pressure data are presented in the form of pressure ratios. Sample tabulations of the data obtained during the test are presented in Appendix III.

APPENDIX I

ILLUSTRATIONS



a. Tunnel assembly



b. Tunnel test section

Fig. 1 Tunnel C

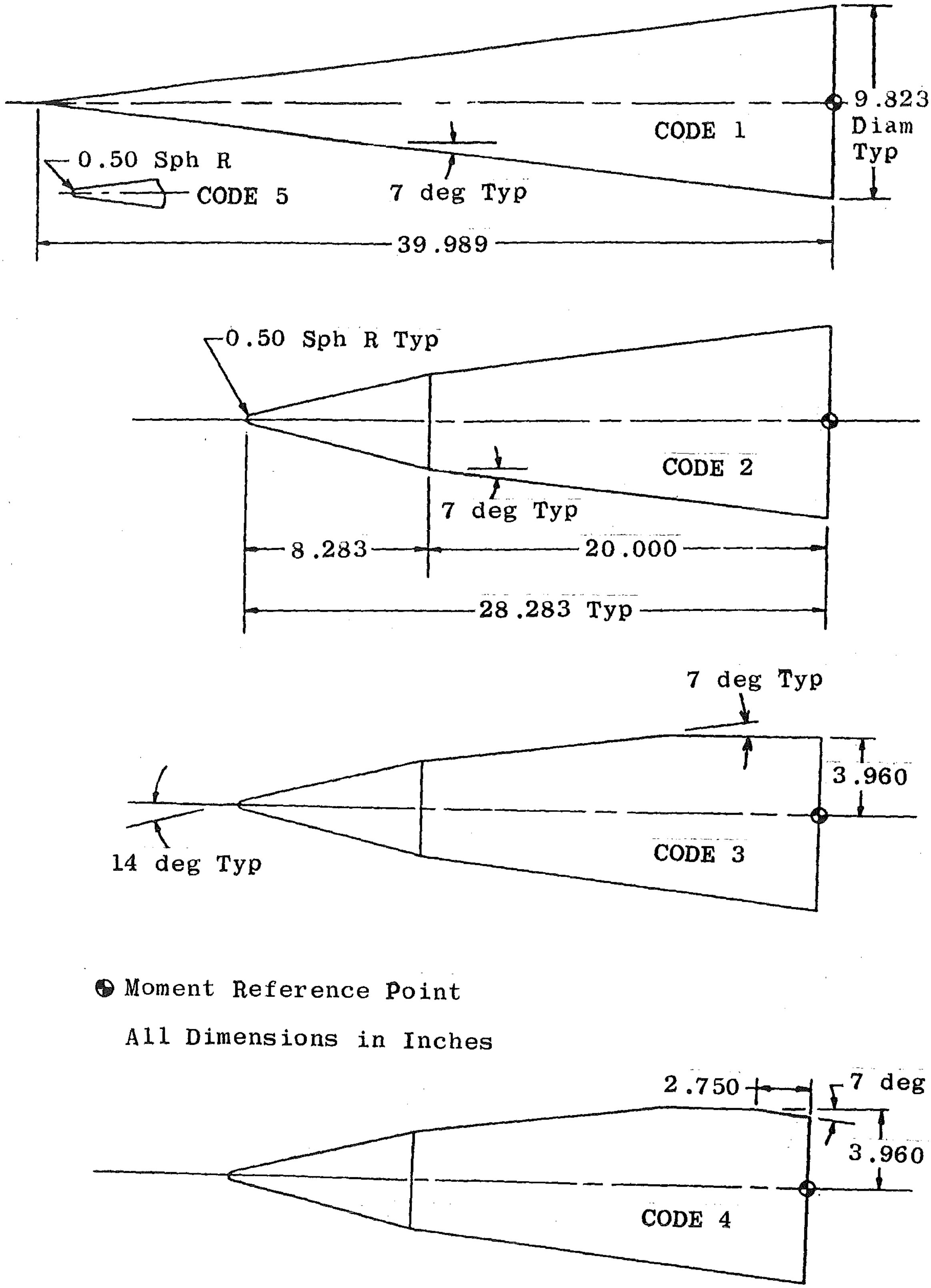


Figure 2. Model details

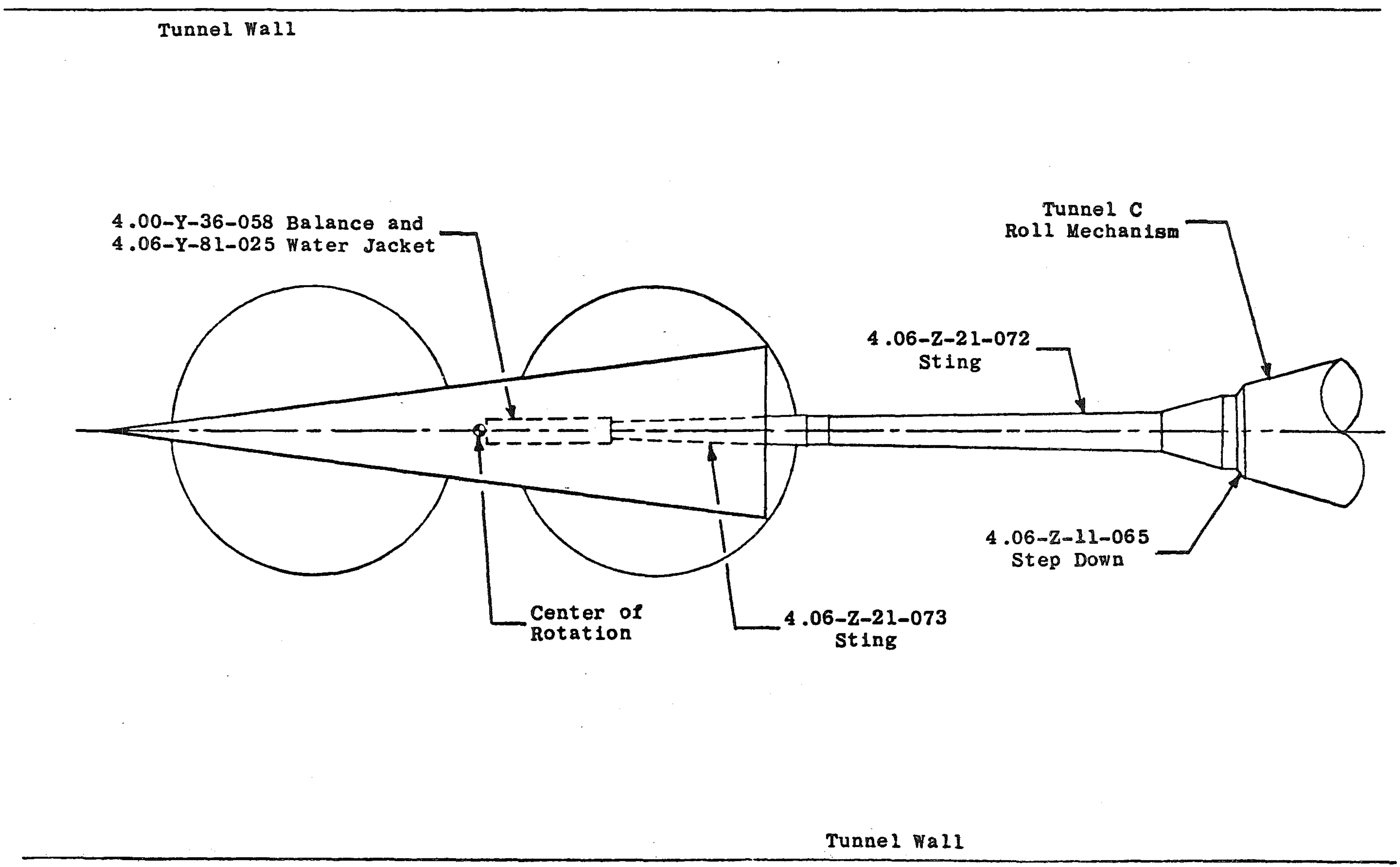


Figure 3. Installation sketch

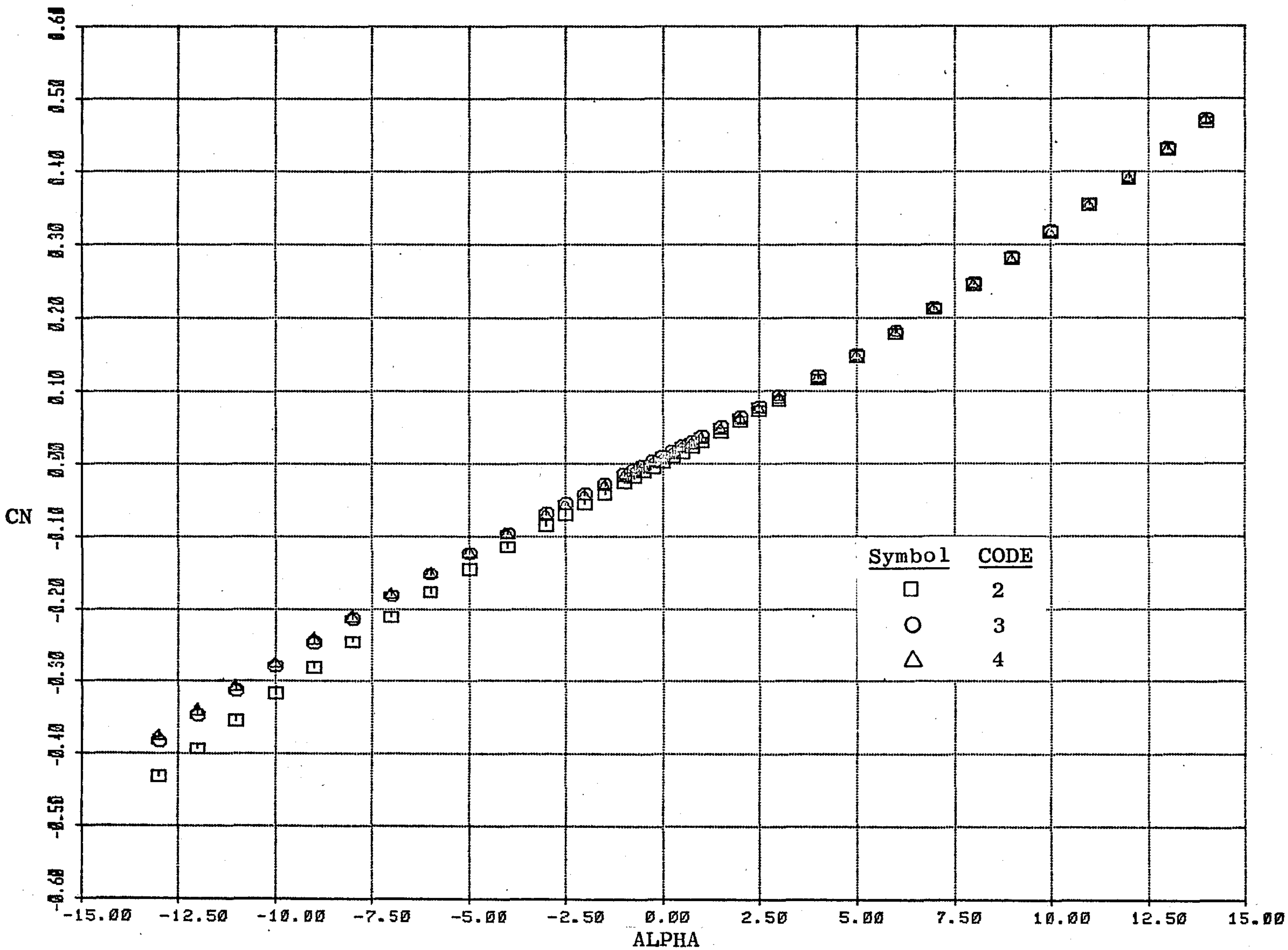


Figure 4. Static-stability and axial-force characteristics of the biconic configurations

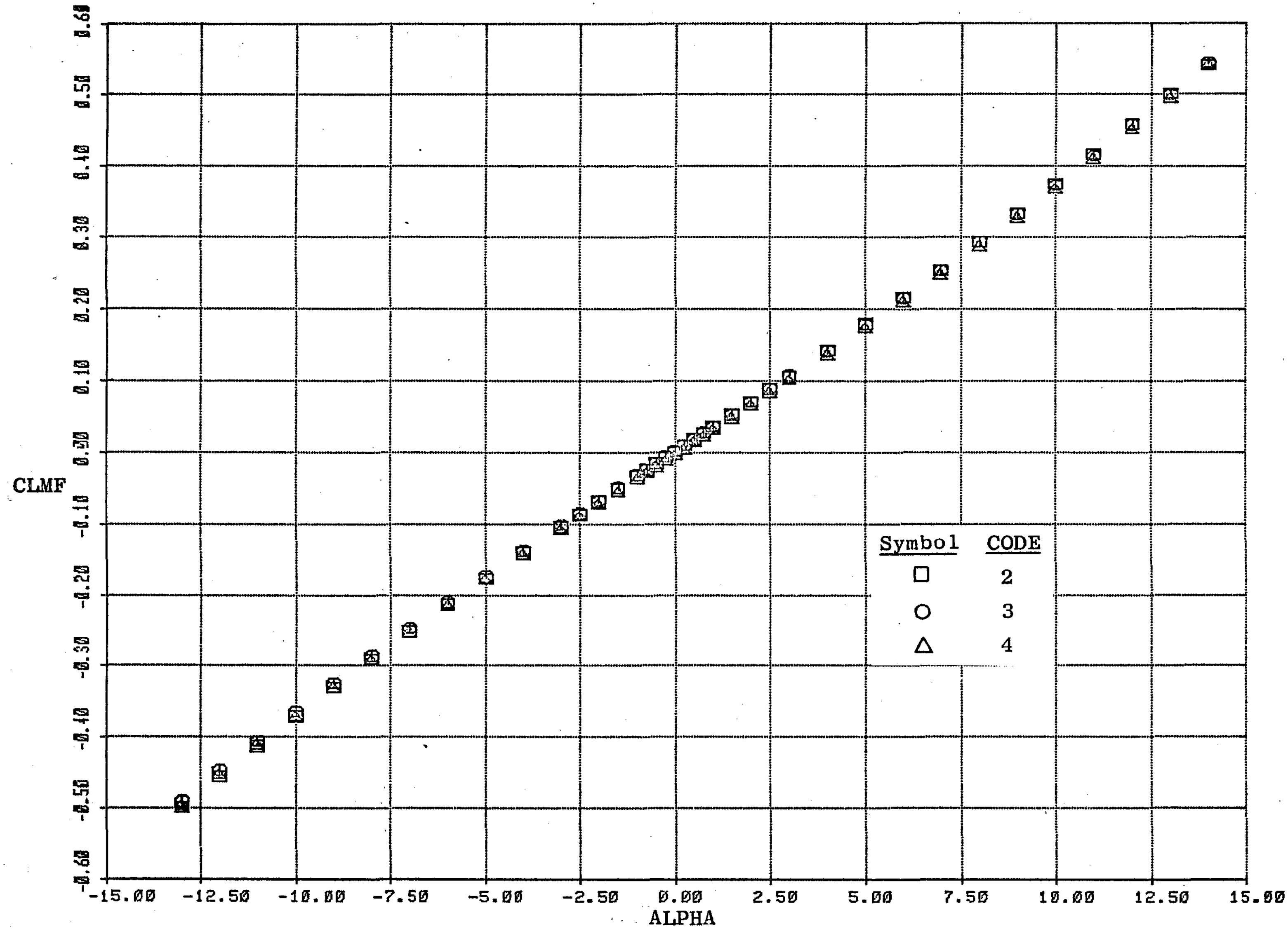


Figure 4. Continued

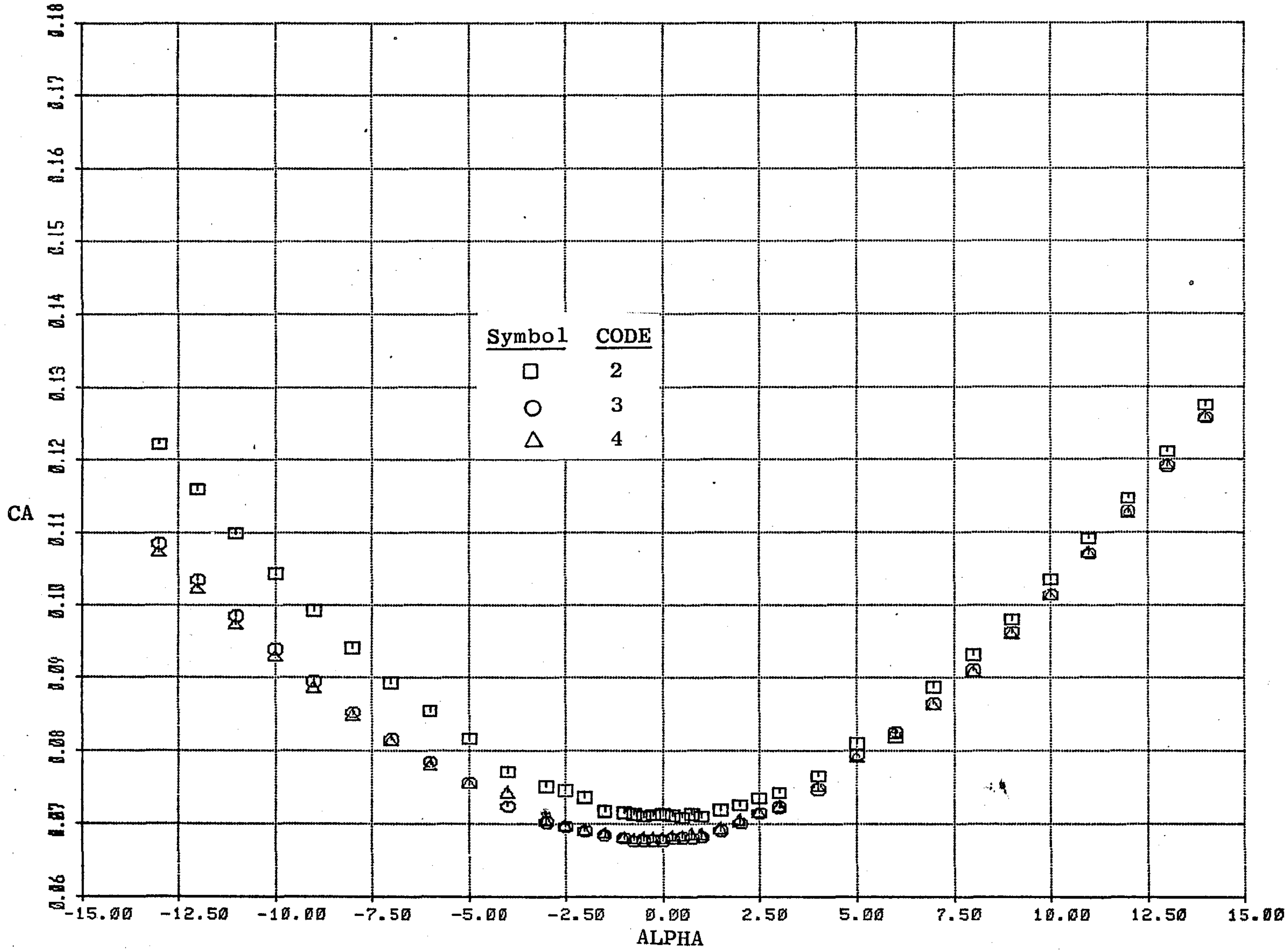


Figure 4. Concluded

APPENDIX II

TABLES

TABLE 1

BALANCE MEASUREMENT ACCURACY

Balance 4.00-Y-36-058

Component	Range of Check Calibration Loads	Measurement Accuracy+
Normal force, lb	±150	±0.5
Pitching moment,* in.-lb	±480	±3.0
Side force, lb	±150	±0.5
Yawing moment,* in.-lb	±480	±2.0
Rolling moment, in.-lb	± 8	±0.1
Axial force, lb	0 to 25	±0.3

*About balance forward moment bridge.

+These values represent a combination of both systematic (bias) and random error contributions of the measured residuals from the static loadings. No evaluation was made of the contribution of individual bias errors in the loads applied, and these are assumed to be zero.

The transfer distance from the balance forward moment bridge to the model moment reference location was -15.472 in. along the longitudinal axis and was measured with an estimated accuracy of ±0.005 in.

TABLE 2

TEST SUMMARY

Data Group Numbers

RE/FT = 1.0×10^6

CODE	ALPHA	PO = 666 psia	PO = 804 psia
1	T1		26
1	S1		27
2	T1	20	1
2	S1	21	2,3,4
2	P1	22	
3	T1	16	5
3	S1	17,19+	6,7
3	P1	18	8,9
4	T1	14	10
4	S1	15	11,12
4	P1		13*
5	T1		23
5	S1		24
5	P1		25

Notes:

1. All data obtained in point-pause mode except for schedule S1.
2. ALPHA schedules, P1:ALPHA = -14 to 14 deg
S1:ALPHA = -14 to 14 deg (sweep mode)
T1: Base pressure stabilization time study at ALPHA = 0
3. Plus (+) indicates data obtained at PHI-T = 180 deg.
4. Asterisk (*) indicates that oil flow data were also obtained at ALPHA = -14, -10, 2, 0, 2, 10, and 14 deg.

APPENDIX III

SAMPLE TABULATED DATA

ARO, INC. - AEDC DIVISION
A SVERDRUP CORPORATION COMPANY
VON KARMAN GAS DYNAMICS FACILITY
ARNOLD AIR FORCE STATION, TENNESSEE
SAMSO/DOTR T.B.L.-PHASE V
PAGE 1

DATE COMPUTED 9-NOV-78
TIME COMPUTED 12:00:00
DATE RECORDED 7-SEP-78
TIME RECORDED 1:19:51
PROJECT NUMBER V41C-33C

GROUP	CODE	CONFIGURATION	RNOSE	SLICES	MACH	PO	TO	Q8	P8	T8	RE/FT	DLP	CR	BALCAL
13	4	14/7 BICONIC	0.5	DOUBLE	10.0	794.3	1902.7	1.254	0.01791	95.1	9.866E+05	0.0277	16.0	5807

NO	ALP-1I	PH1-I	PO	TO	Q8	P8	CAB	PBA/P8	PB1/P8	PB2/P8	PB3/P8	PB4/P8	PB5/P8	PB6/P8	TIME
1	-0.03	0.0	794.3	1902.7	1.254	0.01791	0.00330	0.7498	0.75695	0.7427	0.0000	0.0000	0.0000	0.0000	1:19:51
2	2.00	0.0	797.2	1904.7	1.258	0.01798	0.00427	0.6763	0.69426	0.6583	0.0000	0.0000	0.0000	0.0000	1:21: 5
3	-1.98	0.0	797.8	1904.7	1.259	0.01799	0.00314	0.7621	0.76051	0.7637	0.0000	0.0000	0.0000	0.0000	1:22:11
4	-3.97	0.0	795.8	1908.7	1.256	0.01794	0.00492	0.6268	0.63421	0.6195	0.0000	0.0000	0.0000	0.0000	1:23:53
5	3.99	0.0	795.1	1908.7	1.254	0.01792	0.00414	0.6861	0.69257	0.6796	0.0000	0.0000	0.0000	0.0000	1:25: 3
6	5.98	0.0	800.0	1904.7	1.263	0.01804	0.01074	0.1848	0.21081	0.1588	0.0000	0.0000	0.0000	0.0000	1:25:49
7	-5.96	0.0	798.3	1906.7	1.260	0.01800	0.01106	0.1610	0.18686	0.1352	0.0000	0.0000	0.0000	0.0000	1:32:56
8	-9.94	0.0	799.5	1908.7	1.262	0.01802	0.01109	0.1582	0.18330	0.1331	0.0000	0.0000	0.0000	0.0000	1:34: 0
9	9.97	0.0	792.4	1906.7	1.250	0.01786	0.01047	0.2057	0.22336	0.1880	0.0000	0.0000	0.0000	0.0000	1:37:46
10	13.89	0.0	796.3	1898.7	1.258	0.01797	0.01028	0.2203	0.23135	0.2092	0.0000	0.0000	0.0000	0.0000	1:39:21
11	-13.86	-0.0	798.5	1894.7	1.262	0.01802	0.01091	0.1725	0.19814	0.1469	0.0000	0.0000	0.0000	0.0000	1:42:36

GROUP 13 , PAGE 1

Sample tabulated tunnel conditions data

ARO, INC. - AEDC DIVISION
A SVERDRUP CORPORATION COMPANY
VON KARMAN GAS DYNAMICS FACILITY
ARNOLD AIR FORCE STATION, TENNESSEE
SAMSO/DOTR T.B.L.-PHASE V
PAGE 2

DATE COMPUTED 9-NOV-78
TIME COMPUTED 12:00:00
DATE RECORDED 7-SEP-78
TIME RECORDED 1:19:51
PROJECT NUMBER V41C-33C

GROUP	CODE	CONFIGURATION	RNOSF	SLICES	MACH	PO	TO	QR	P8	T8	RE/FT	DLP	CR	BALCAL
13	4	14/7 BICONIC	0.5	DOUBLE	10.0	794.3	1902.7	1.254	0.01791	95.1	9.866E+05	0.0277	16.0	5807

NO	ALPHA	BETA	PHI-T	CN	CLMF	CY	CLN	CLL	CAT	CAB	CA	CLMF/CN	CLN/CY	CLM
1	0.11	-0.09	0.0	0.0129	0.00510	0.0067	0.00832	0.00008	0.0720	0.0033	0.0687	0.395	1.246	0.00499
2	2.17	-0.09	0.0	0.0682	0.07720	0.0071	0.00883	0.00011	0.0761	0.0043	0.0718	1.132	1.242	0.07705
3	-1.86	-0.09	0.0	-0.0381	-0.06227	0.0063	0.00797	0.00008	0.0736	0.0031	0.0704	1.636	1.266	-0.06238
4	-3.89	-0.10	0.0	-0.0915	-0.13429	0.0062	0.00783	0.00008	0.0782	0.0049	0.0733	1.468	1.273	-0.13446
5	4.18	-0.09	0.0	0.1247	0.14811	0.0075	0.00920	0.00015	0.0810	0.0041	0.0769	1.187	1.227	0.14796
6	6.20	-0.09	0.0	0.1863	0.22452	0.0083	0.01029	0.00017	0.0960	0.0107	0.0853	1.205	1.233	0.22414
7	-5.91	-0.09	0.0	-0.1487	-0.20921	0.0070	0.00879	0.00007	0.0903	0.0111	0.0793	1.407	1.253	-0.20960
8	-9.96	-0.10	0.0	-0.2733	-0.36823	0.0068	0.00863	0.00003	0.1055	0.0111	0.0944	1.347	1.259	-0.36863
9	10.23	-0.09	0.0	0.3246	0.38380	0.0102	0.01231	0.00018	0.1155	0.0105	0.1050	1.182	1.201	0.38343
10	14.20	-0.09	0.0	0.4780	0.55650	0.0124	0.01449	0.00022	0.1396	0.0103	0.1293	1.164	1.172	0.55614
11	-13.93	-0.09	-0.0	-0.4126	-0.53974	0.0080	0.00984	-0.00001	0.1244	0.0109	0.1135	1.308	1.230	-0.54013

GROUP 13 , PAGE 2

Sample tabulated static-stability data